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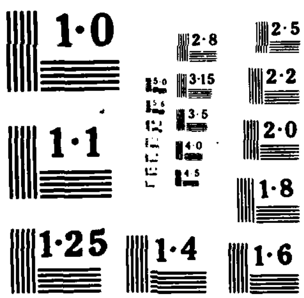
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STRUCTURES TECHNICAL MEMORANDUM 397

FURTHER INVESTIGATIONS TO IMPROVE THE FATIGUE LIFE OF THE MIRAGE IIIO WING MAIN SPAR

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SUMMARY

Wing main spars of Mirage IIIO aircraft have undergone a refurbishment program to extend their fatigue lives by the installation of interference-fit steel bushes. A supplementary investigation has been carried out to assess two potential techniques for reducing the influence of empty rivet holes (namely the installation of interference-fit steel pins and adhesively-bonded aluminium rivets), and to assess the improvements in fatigue life which might be introduced by a redesign of the spar at the previously critical location.

It was found that both treatments of the rivet holes resulted in a further small improvement in the life of specimens refurbished with interference-fit steel bushes at the bolt holes, and that these lives were not significantly different from that of specimens of the new design of spar in which the cross-sectional area was increased and the rivet holes omitted. However, considerable improvements in life were obtained when the bolt holes in the "redesigned spar" specimens were either cold-expanded (a factor of 4.1) or had interference-fit steel bushes installed in them (a factor of 3.4).

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CONTENTS

1. INTRODUCTION

Investigations carried out at the Aeronautical Research Laboratories (ARL) (Ref. 1) led to the adoption of the interference-fit bushing of critical bolt holes as a technique for improving the fatigue life of the wings of Mirage IIIO aircraft in the fleet of the Royal Australian Air Force (RAAF). The two Single-Leg-Anchor-Nut (SLAN) rivet holes adjacent to bolt hole (1) on the rear flange of the main spar were reamed to 4 mm in diameter and left empty, the SLAN itself being attached to a redesigned L-Shaped shim which incorporated the gang-nut strip holding the captive nuts for the next four bolts. The implementation of the wing spar refurbishment in fleet aircraft is described in Reference 2.

An alternative treatment proposed by the Eidgenoessisches Flugzeugwerk (F+W), Switzerland as a reworking technique for the SLAN rivet holes was to insert interference-fit steel pins. Research at ARL (Ref. 3) suggested that the fatigue life of the critical section might be improved by adhesively-bonding close-fit rivets into the SLAN rivet holes. A redesign of the main spar provided a thicker and wider flange at the critical section and omitted all rivet holes adjacent to the first five bolts in the rear flange. An extension of this proposal was that the bolt holes be cold-expanded using the Boeing split-sleeve process (Ref. 4) which had been studied during previous investigations (Refs 5, 6) to improve the life of the spar.

At the request of the F+W, ARL undertook a program of fatigue tests to investigate these proposals with specimens similar to those used to develop the refurbishment scheme for the inboard lower rear flange section of the Mirage III main spar. The results of the investigation are given in this report.

2. SPECIMENS AND TESTING CONDITIONS

2.1 Test specimens

A detail of the rear lower surface of the original design of Mirage main spar at the SLAN section is shown in Fig. 1. The testing program involved seven different groups of specimens, details of which are given below. The basic "control" specimen configuration, Group E (which was identical to that used in the previous investigation - Ref. 1), is shown in Fig. 2.

(a) Group A - represented the F+W Swiss test wing refurbishment scheme, i.e. the original spar section but refurbished with an 11 mm external diameter (8 mm internal diameter) 0.3% interference-fit type 304 stainless steel bush at the SLAN bolt hole and 13 mm external diameter bushes at the other four bolt holes. Details of the bushes are given in Reference 1. Two 3.7 mm diameter interference-fit pins (Fig. 3) of 30NCD16 steel were inserted in the SLAN rivet holes to provide an interference of 0.05% to 0.3%.

The other rivet holes were cold expanded (1.8% to 2.4%) to a final diameter of 3.65 mm and left empty. Although the L-shaped gang-nut shim sub-assembly (Fig. 4) was incorporated it was not riveted to the specimen. Further details of this type of specimen are given in the Appendix 1.

(b) Group B - represented the new design of spar having a section at the rear flange 3 mm thicker and 3 mm wider than the original (Ref. 7), i.e. in Section A-A on Fig. 2, the dimensions 11, 31.5 and 8.6 mm became 14 mm (an increase in hole edge distance of 3 mm), 34.5 and 5.6 mm respectively and the corresponding dimensions in Section B-B 18, 29 and 5.6 mm. Bolt holes were reamed to 8.3 mm diameter (hole (1)) and 10.3 mm diameter (holes (5), (6), (8), (9)), and all rivet holes were omitted. The L-shaped gang-nut strip shim sub-assembly was incorporated.

(c) Group C - identical to Group B except that the bolt holes were cold-expanded (3.6%) by the Boeing split-sleeve process to finish at 8.3 mm and 10.3 mm diameter respectively after post cold-expansion reaming. The slits in the sleeves were oriented on the spanwise axis of the holes on the outboard side, and the sequence of cold-expansion was holes (1), (5), (6), (8) and (9). A profile of the deformation along the side of a specimen adjacent to the bolt holes after cold-expansion is shown in Fig. 5(a). Measurements were also made of the out-of-plane deformation adjacent to the holes at the entry and exit points of the cold-expansion mandrel. These are listed in Fig. 5(b), while a photo of the exit surface after careful filing to remove the deformation lips is shown in Fig. 6. At all four diametral positions the deformation was greater at the exit face than at the entry face of the mandrel, the greatest difference (on average) being at position (b) which corresponded to that of the slit in the split sleeve.

(d) Group D - identical to Group B except that 11 mm and 13 mm external diameter type 304 stainless steel interference-fit (0.3%) bushes were incorporated, with the bores to take 8.3 mm and 10.3 mm diameter bolts respectively - bush diametral ratios of 1.33 and 1.26.

(e) Group E - standard 0.125 inch diameter SLAN rivet "control" specimens representing the original spar section.

(f) Group F - represented one of the refurbishment options reported in Reference 1, i.e. 11 mm and 13 mm external diameter (8 mm and 10.3 mm internal diameter) interference-fit bushes similar to Group A specimens and incorporating the L-shaped gang-nut shim assembly. However the SLAN rivet holes were simply reamed to 5/32 inch (nominal 4 mm) diameter and left empty, and the gang-nut assembly was attached to the specimen by three 5/32 inch diameter 2117 aluminium alloy rivets.

(g) Group G - identical to Group F except that the SLAN rivet holes were filled with adhesively-bonded close-fit 2117 aluminium alloy rivets of 5/32 inch diameter, using Araldite K138 epoxy resin adhesive. Details of the hole preparation procedures, etc. are given in Appendix 2.

2.2 Fatigue testing program

The testing program involved 32 specimens, five in each of Groups F and G, four in each of Groups A, B, C and D and six in Group E. All specimens were taken from one 55 mm thick plate (Fig. 7) of A7-U4SG-T651 aluminium alloy (ARL designation GZ1) with their axes parallel to the rolling direction of the plate. Tension and compact tension fracture toughness specimens were taken from broken fatigue specimens as indicated in Fig. 8. The results of the tension and fracture toughness tests, together with the chemical composition of the plate GZ1 are given in Table 1.

All fatigue specimens were tested under the same French 100-flight sequence (Fig. 9) which had been used in the previous ARL investigations relating to the Mirage life enhancement (Refs 1, 5, 6). The stress/g relationship was linear. For all groups of specimens the testing machine force corresponding to the +7.5 g load of the sequence was nominally 404 kN (91,000 lbf). Specimens in Groups A, E, F and G all had the 'original' spar dimensions, and the +7.5 g load represented a gross-area stress at the SLAN section of 180 MPa - with an associated 1 g stress of 24 MPa. The specimens in Groups B, C, and D had a gross area nominally 1.09 times those in Groups A, E, F and G. Thus the +7.5 g gross-area stress at the SLAN section for the specimens in Groups B, C and D was 165 MPa and the 1 g stress 22 MPa. In the case of the two control Groups (B and E) the nett-area ratio at the SLAN section was 1.21.

3. FATIGUE TEST RESULTS

The individual test results and details of the fractures are given in Table 2. Of the 32 specimens tested, four failed at locations other than the SLAN section. These included one of Group A, two of Group C and one of Group D. The two sets of average lives for Groups A, C and D given in Table 2 assume that, firstly, non-failure at the SLAN section represented a "run-out" at that section and, secondly, that non-failure at the SLAN section represented an invalid test result.

Some typical fracture surfaces are shown in Fig. 10. In specimens of Group E (Fig. 10(a)) the main fatigue cracking developed from the "rear" side of the SLAN bolt hole - as had been previously reported in Reference 1 - and similar cracking characteristics were exhibited by specimens of Groups B, C and D (Figs 10(c), (d) and (f)) except that the extent of the fatigue cracking was greater and embraced most of the area at the rear of the bolt hole. The major fatigue crack development in specimens of Groups A (Fig. 10(b)), F and G was from the first SLAN rivet hole, i.e. that next to the bolt hole, again similar to that which occurred in the bushed bolt hole specimens referred to in Reference 1.

4. DISCUSSION

The average life of specimens incorporating interference-fit steel pins at the SLAN rivet holes (Group A) is 15053 flights. This is significantly greater (at the 5% level of significance) than the pooled average life (10642 flights) of similar specimens with the SLAN rivet holes treated in a variety of ways (i.e. reamed or cold-expanded, open or filled with close-fit rivets) which was reported in Reference 1, and the average life (9242 flights) of the open-hole Group F specimens. These findings support those in Reference 8 where it was reported that the reduction in fatigue life associated with open holes in aluminium alloy could be lessened by plugging them with a harder material. Specimens incorporating adhesive-bonded SLAN rivets (Group G) had an average life of 12182 flights which is significantly greater than those of Group F, but significantly less than those of Group A. Compared to specimens with open holes (Group F) the improvement in life of specimens incorporating bonded rivets is much less (a life ratio of only 1.32) than the ratio of about 2.6 reported in Reference 3 for simple specimens having similar hole treatments.

Increasing the gross-section area at the SLAN section by about 9% (Group B) resulted in an average life of 12885 flights, which is double that of the Group E specimens representing the "original" design of spar. This is consistent with the estimated increase in life by a factor of about two using the reduced gross-area stress and the life/stress relationship indicated in Reference 3; and an increase in life of from 40% to 130% which was predicted in Reference 7. However, the average life of the "redesigned spar" Group E specimens is not

significantly different to those of the refurbished "original" design specimens in Groups A and G. The omission of the SLAN rivet holes in the redesigned spar removed this feature as a source of fatigue crack initiation and allowed the potential benefits of hole cold-expansion to be more fully realised, i.e. a life ratio of 4.1 for the Group C compared to the Group B specimens with non-cold-expanded holes.

This effect is also reflected in the change in failure location of the cold-expanded hole specimens covered by this investigation and those tested previously (Ref. 1) which failed "prematurely" at the SLAN rivet holes because these were within the bounds of the balancing tensile stress field resulting from the cold-expansion of the bolt hole. Specimens incorporating interference-fit bushes (Group D) also demonstrated a significant increase in fatigue life compared to those of Group B - a life ratio of 3.3. The lower lives of the interference-fit bushed hole specimens compared to the cold-expanded hole Group C specimens (life ratio of about 0.8) is probably attributable to the 4.4% smaller nett-section area of the bushed hole specimens at the SLAN section.

It should be noted that the average life (6199 flights) of the "control" specimens (Group E) taken from plate GZ1 which was used exclusively in the current investigation, is significantly less than the average life of 8213 flights of the "control" group of specimens incorporating 0.125 inch SLAN rivets which were taken from the four batches of A7-U4SG plate used previously (Ref. 1).

5. CONCLUSIONS

1. Fatigue tests on specimens representing a redesigned Mirage III wing main spar have shown that the fatigue life may be doubled by adopting a section of greater cross-sectional area and by omitting rivet holes at the previously critical location.

2. Even greater improvements in life can be obtained by either cold-expanding or bushing the bolt holes in the redesigned spars, the increases (compared to specimens having reamed holes only) being by factors of about 4.1 and 3.4 respectively.

3. Existing spars of the original design which are potentially capable of refurbishment by the insertion of interference-fit bushes at the bolt holes may have their fatigue lives further extended by the installation of either interference-fit steel pins or adhesively-bonded rivets at the SLAN rivet holes.

ACKNOWLEDGEMENTS

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APPENDIX 1

DETAILS OF BUSHED SPECIMENS, GROUPS A, D, F AND G

In all cases Type 304 stainless steel was used for the bushes (UTS = 1017 MPa) and the sequence of bush insertion was holes (9), (8), (6), (5) and (1).

Group A

Hole (1) bush external diameter 11 mm, internal 8 mm; bolt holes (5) to (9) bush external diameter 13 mm, internal 10 mm.

Before bush insertion, outer surface of bush and surface of hole in specimen coated with DOW Corning Molykote BR2 grease.

All bushes finished proud of the skin face by about 5 mm and protruded into clearance-fit holes in the skin plate.

Holes were provided in the skin plate to accommodate the interference-fit steel pins in the SLAN rivet holes. Molykote BR2 grease was also used as a lubricant during the insertion of the pins.

Groups D, F and G

Before bush insertion, outer surface of bush coated with a light oil and the surface of the hole in the specimen coated with Bolicone grease 73.

In all cases, for bolt holes (5) to (9) the bush external diameter was 13 mm and internal diameter 10.3 mm. At bolt hole (1), Group D specimens incorporated an 11 mm outside diameter bush with internal diameter of 8.3 mm, whereas for Groups F and G specimens the bush internal diameter was 8 mm.

APPENDIX 2

INSTALLATION OF ADHESIVELY-BONDED RIVETS

The procedure adopted for the installation of the adhesively-bonded 2117 aluminium alloy rivets at the SLAN section of the Group G specimens was as follows:

(a) Rivets matched to individual rivet holes, providing a clearance estimated to be not greater than about 0.01 mm on diameter.

(b) Rivet holes cross-honed with stainless steel wire brushes in a rotary, air-driven tool.

(c) Rivets and rivet holes degreased using Methyl Ethyl Ketone (MEK).

(d) Surface of rivet holes coated with Araldite K138 epoxy resin, worked into the holes from both ends using a non-cotton wool applicator.

(e) Rivets thoroughly coated with adhesive.

(f) Rivets (in the sequence: hole (2) then hole (3)) pressed into holes by hand and then tapped in to seat in the countersinks of the holes in the specimens.

(g) Excess adhesive wiped from both faces of the specimen.

(h) Adhesive allowed to cure for at least 48 hours at room temperature.

(i) Rivets dressed flush with both faces of the specimen.

TABLE 1

PROPERTIES OF TEST MATERIAL

(a) Chemical Composition

* Specification A7-U4SG (%)	Plate serial No. GZ1 $^{\phi}$
Cu 3.9 -5.0	4.50
Mg 0.2 -0.8	0.36
Mn 0.4 -1.2	0.54
Fe 0.30 max	0.20
Si 0.5 -1.2	0.72
Ti 0.15 max	0.01
Cr 0.10 max	) Not analysed
Zn 0.25 max	)

(b) Static Tensile

	* Specification A7-U4SG	Plate serial No. GZ1 $^{\phi}$
0.1% proof stress (MPa)	-	451
0.2% proof stress (MPa)	390	457
Ultimate stress (MPa)	450	502
Elongation (%) 5.65 $\sqrt{A}$	5	10.7
0.1% PS/Ult	-	0.90

(c) Fracture toughness $^{\phi}$

31.3 $MPa.m^{\frac{1}{2}}$

* Conditions de controle des produits lamines en alliages d'aluminium utilises dans les constructions aerospatiales.
Ministere de la Defense, Direction Technique des Construction Aeronautiques AIR 9048, Edition No. 1, 26 Dec. 1978, p.91.

$^{\phi}$ Average of four individual results

TABLE 2

TABLE 2 (a) GROUP A - "Original" spar section, 11 mm diameter interference-fit bush at hole (1), interference-fit steel pins inserted in SLAN rivet holes.

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1C4	13300	351	Large cracks both sides of hole (2). Crack rear side of hole (1). Small cracks forward side of hole (3).
GZ1B7	15831	345	Large cracks both sides of hole (2). Crack rear side of hole (1). Large crack forward side of hole (3).
GZ1B10	16200	331	Ditto.
GZ1B1	23900	349	Failed through hole (9). Crack initiated at rear side of hole near tapered shim face.

Log. average life and s.d. of log. life (including all four results) 16897 flights and 0.107.

Log. average life and s.d. of log. life (excluding GZ1B1) 15053 flights and 0.047.

TABLE 2 (b) GROUP B - "New" spar design, reamed bolt holes (8.3 and 10.3 mm diameter) but no through-the-flange rivet holes.

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1C7	12742	392	Large cracks both sides of hole (1).
GZ1C5	9442	386	Ditto.
GZ1C3	15542	391	Ditto.
GZ1B6	14742	355	Ditto.

Log. average life 12885 flights, s.d. of log. life 0.097.

TABLE 2 (c) GROUP C - "New" spar design, bolt holes cold-expanded to 8.3 mm and 10.3 mm diameter, no through-the-flange rivet holes.

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1C6	61742	397	Very large crack rear side of hole (1). Crack forward side of hole (1).
GZ1C1	46042	387	Ditto.
GZ1B3	69942	398	Failed through hole (5). Crack initiation by fretting under skin plate near step in section. Large cracks on surface from hole (1).
GZ1B12	56342	398	Ditto.

Log. average life and s.d. of log. life (including all four results) 57853 flights and 0.076.

Log. average life and s.d. of log. life (excluding GZ1B3 and GZ1B12) 53317 flights and 0.090.

TABLE 2 (d) GROUP D - "New" spar design, 11 mm and 13 mm stainless steel interference-fit bushes in bolt holes, no through-the-flange rivet holes.

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1B2	53042	393	Very large crack rear side of hole (1). Crack forward side of hole (1).
GZ1B5	44742	392	Ditto.
GZ1C2	33842	387	Ditto.
GZ1B8	48742	384	Failed through hole (9). Surface fretting initiated crack under tapered shim at rear side of hole.

Log. average life and s.d. of log. life (including all four results) 44481 flights and 0.085.

Log. average life and s.d. of log. life (excluding GZ1B8) 43145 flights and 0.099.

TABLE 2 (e) GROUP E - "Original" spar section, control specimens with 0.125 inch SLAN rivets

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1B4	5652	351	Large crack rear side of hole (1). Crack forward side of hole (1). Small cracks rear side of hole (2).
GZ1C8	4742	400	Large crack rear side of hole (1). Crack forward side of hole (1).
GZ1B9	6842	392	Large crack rear side of hole (1). Crack forward side of hole (1). Small cracks both sides of hole (2).
GZ1D4	7650	348	Ditto.
GZ1C12	6924	339	Ditto + small cracks forward side of hole (3).
GZ1D10	5844	351	Ditto GZ1B9.

Log. average life 6199 flights, s.d. of log. life 0.075

TABLE 2 (f) GROUP F - "Original"spar section, 11 mm diameter interference-fit bush at hole (1), SLAN rivet holes reamed to 5/32 inch diameter and left empty.

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1D9	9512	343	Crack rear side of hole (1). Large cracks both sides of hole (2). Large crack forward side of hole (3).
GZ1D11	9642	397	Ditto.
GZ1D7	9642	No record	Ditto.
GZ1D5	10742	398	Ditto.
GZ1C10	7828	351	Large crack rear side of hole (1). Large cracks both sides of hole (2). Crack forward side of hole (3).

Log. average life 9242 flights, s.d. of log. life 0.051

TABLE 2 (g) GROUP G - "Original" spar section, 11 mm diameter interference-fit bush at hole (1), SLAN rivet holes reamed to 5/32 inch diameter and filled with adhesively bonded close-fit 2117 aluminium alloy rivets.

SPECIMEN NO.	FLIGHTS TO FAILURE	FAILING LOAD (kN)	FAILURE DETAILS
GZ1D12	13902	341	Crack rear side of hole (1). Large cracks both sides of hole (2). Crack forward side of hole (3).
GZ1D6	10342	400	Ditto.
GZ1C9	11990	350	Ditto.
GZ1D8	12625	350	Ditto except large crack forward side of hole (3).
GZ1C11	12326	350	Ditto GZ1D12

Log. average life 12182 flights, s.d. of log. life 0.047

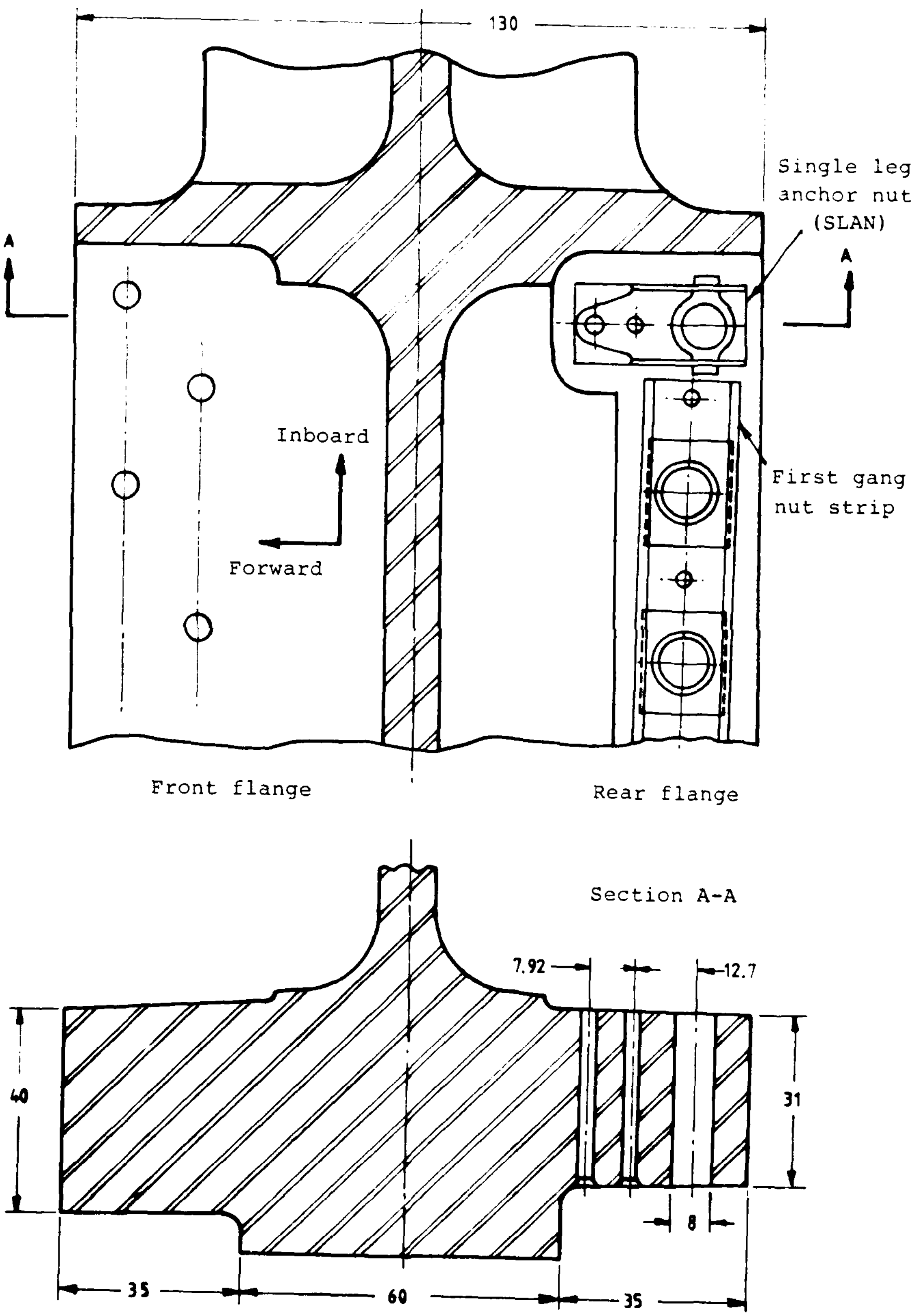


FIG. 1 MIRAGE IIIO SPAR - LOWER SURFACE AT SLAN SECTION

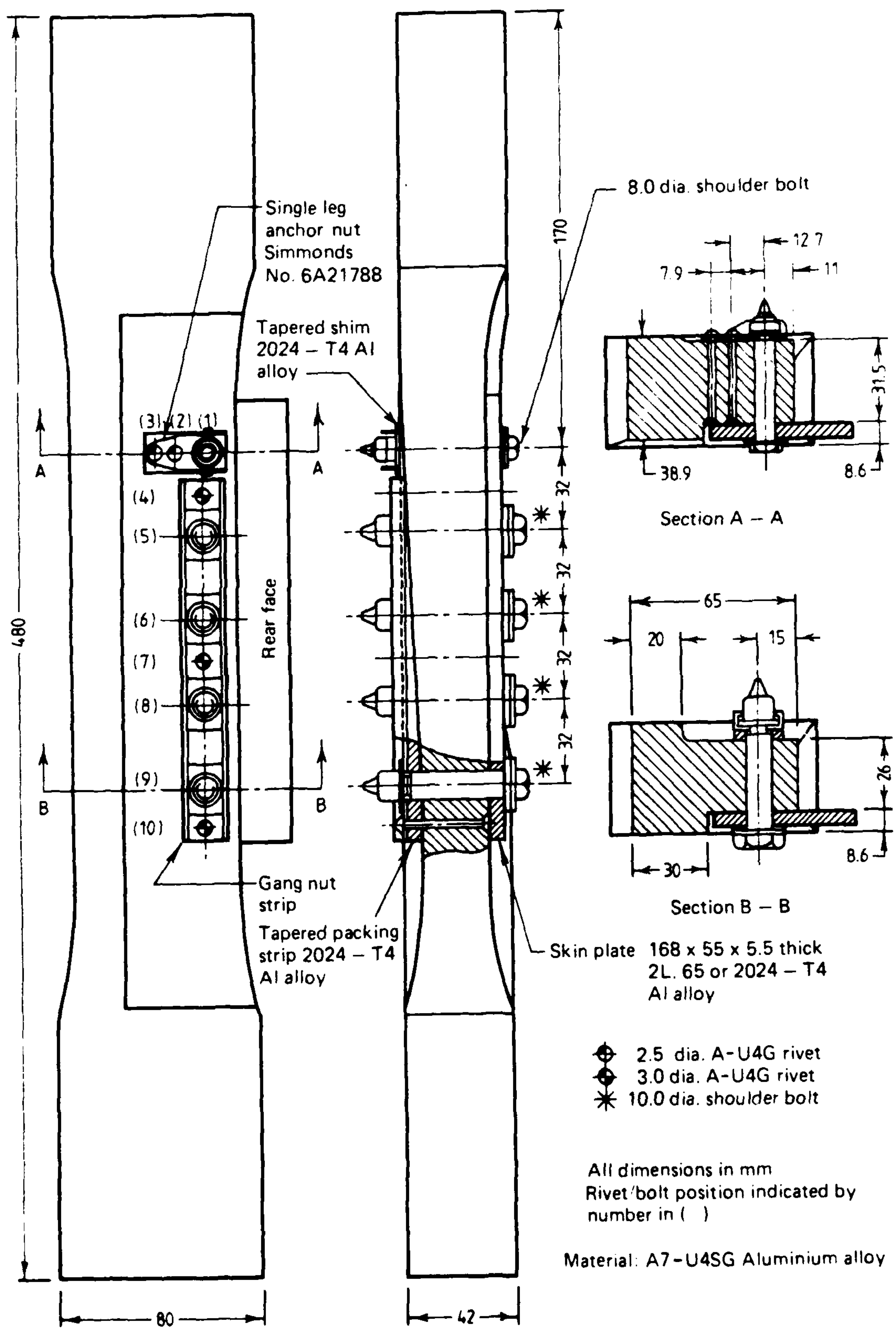
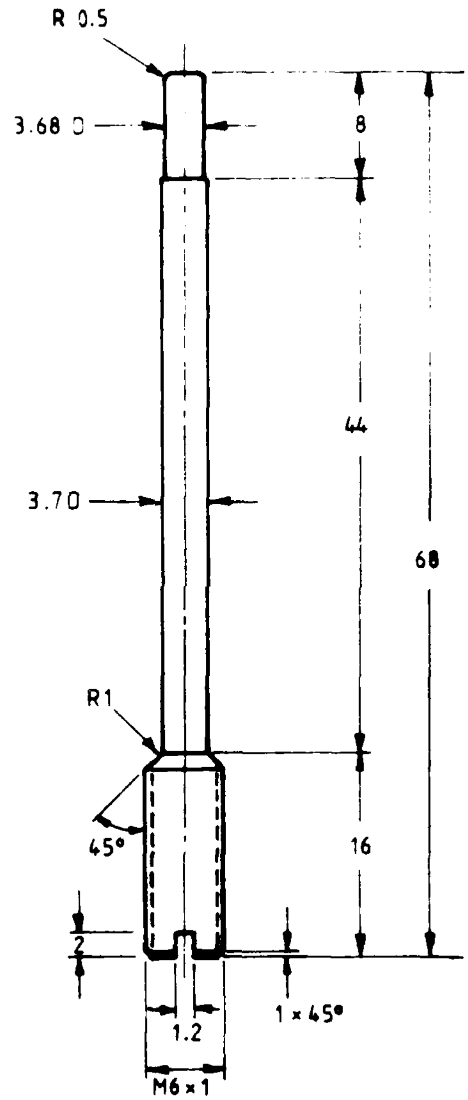
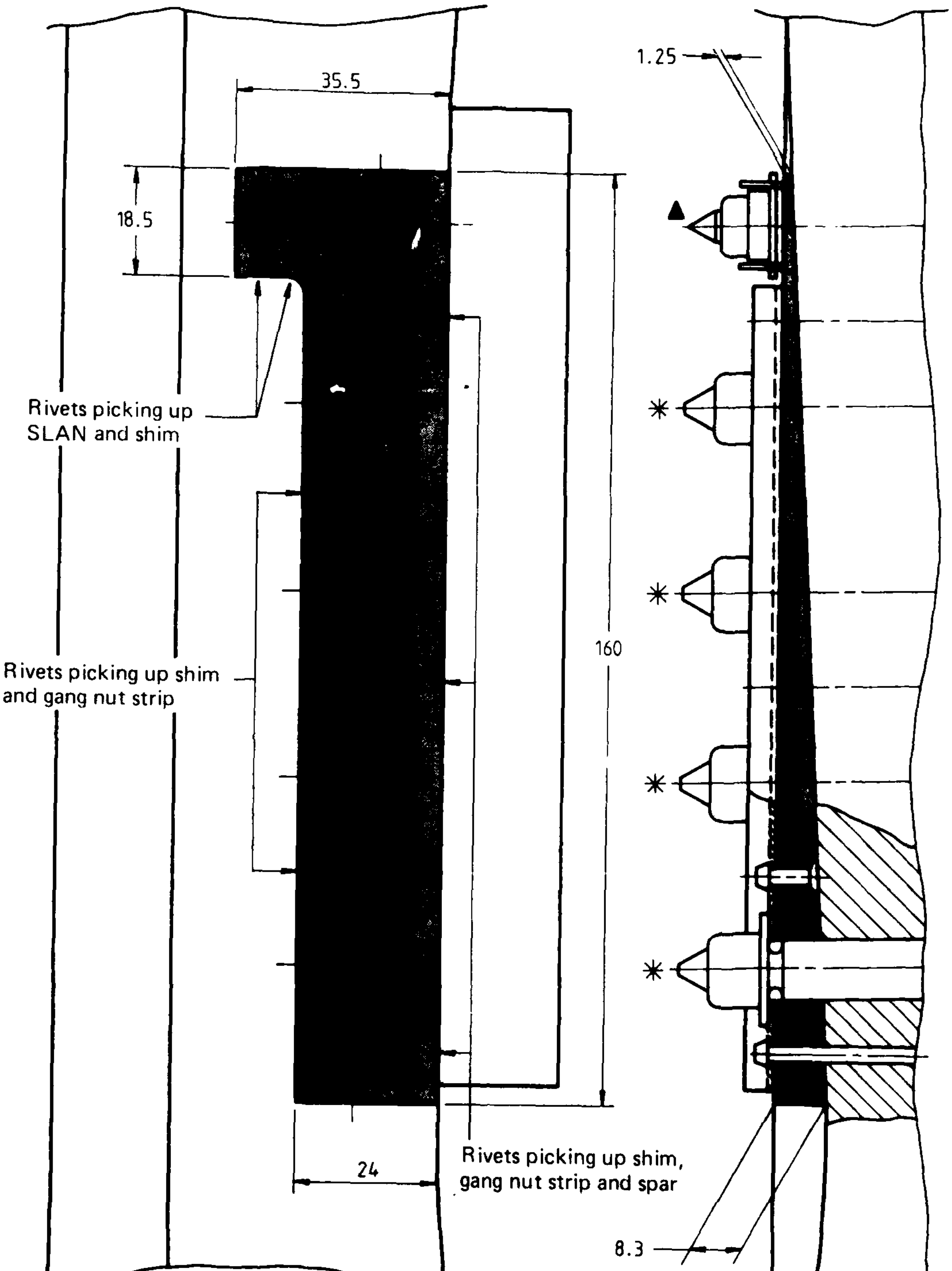


FIG. 2 MIRAGE SPAR LOWER REAR FLANGE FATIGUE SPECIMEN



Material 3ONCD16 steel, UTS 1080 TO 1230 MPa

FIG. 3 INTERFERENCE FIT STEEL PIN
FOR SLAN RIVET HOLES

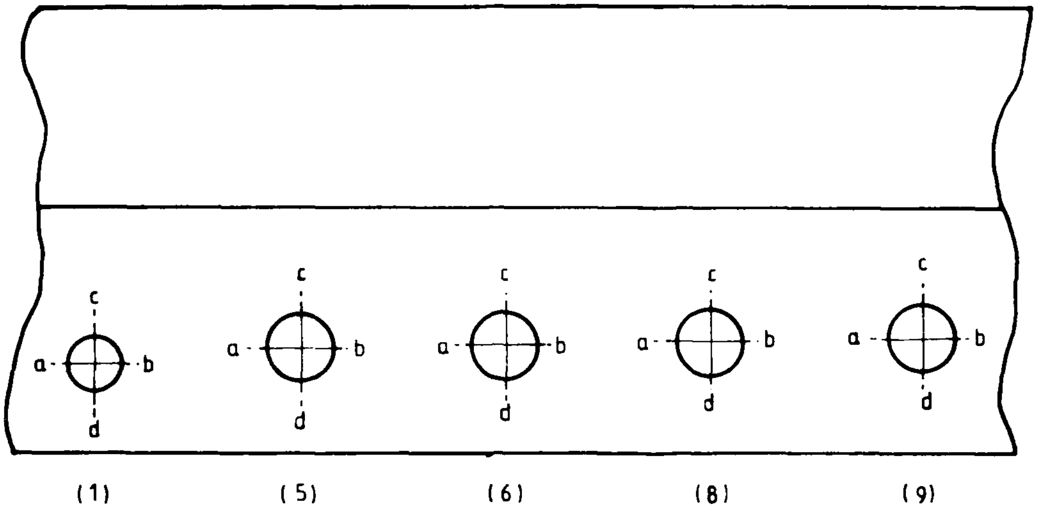


All dimensions in mm

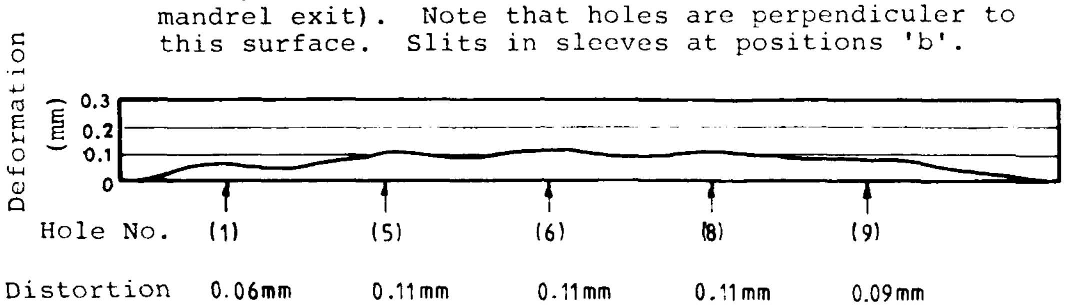
- ✳ 10 dia. shoulder bolt
- ▲ 8 dia. shoulder bolt
- 3 dia. A - U4G rivet
- 2.5 dia. A - U4G rivet
- 4 dia. A - U4G rivet

Modified design shim

FIG. 4 MODIFIED GANG NUT STRIP/SLAN ASSEMBLY
(Shown fitted to original design of spar)



Skin-plate surface of specimen (hole cold-expansion mandrel exit). Note that holes are perpendiculer to this surface. Slits in sleeves at positions 'b'.



(a) Deformation at side of specimen adjacent to bolt holes

Diametral position	Hole number					Average
	(1)	(5)	(6)	(8)	(9)	(5) to (9)
Skin plate surface						
a	0.058	0.053	0.046	0.041	0.046	0.047
b	0.122	0.086	0.074	0.074	0.061	0.074
c	0.091	0.097	0.102	0.107	0.084	0.098
d	0.094	0.130	0.124	0.104	0.152	0.128
Gang-nut strip surface						
a	0.023	0.036	0.028	0.036	0.046	0.037
b	0.025	0.030	0.025	0.023	0.025	0.026
c	0.064	0.076	0.081	0.064	0.061	0.070
d	0.061	0.089	0.064	0.084	0.084	0.080

(b) Out-of-plane deformations at edges of holes

FIG. 5 DEFORMATIONS ASSOCIATED WITH COLD-EXPANSION OF HOLES (SPECIMEN NO. GZ1B12)

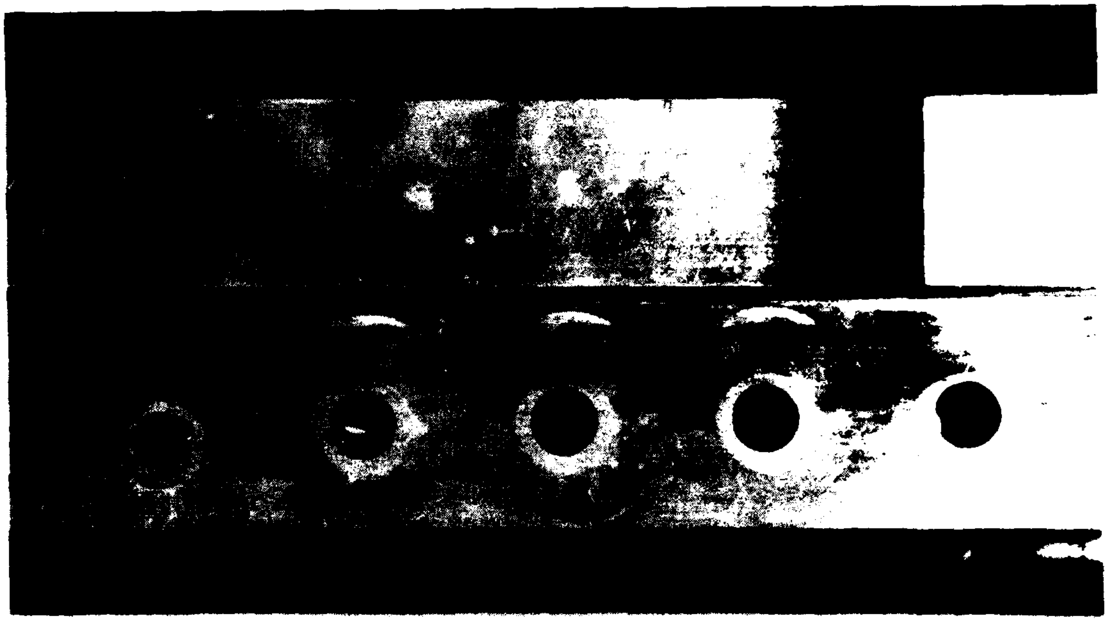


FIG. 6 SPECIMEN GZ1B12. EXTENT OF SURFACE DEFORMATION ON SKIN-PLATE SURFACE AROUND COLD-EXPANDED HOLES

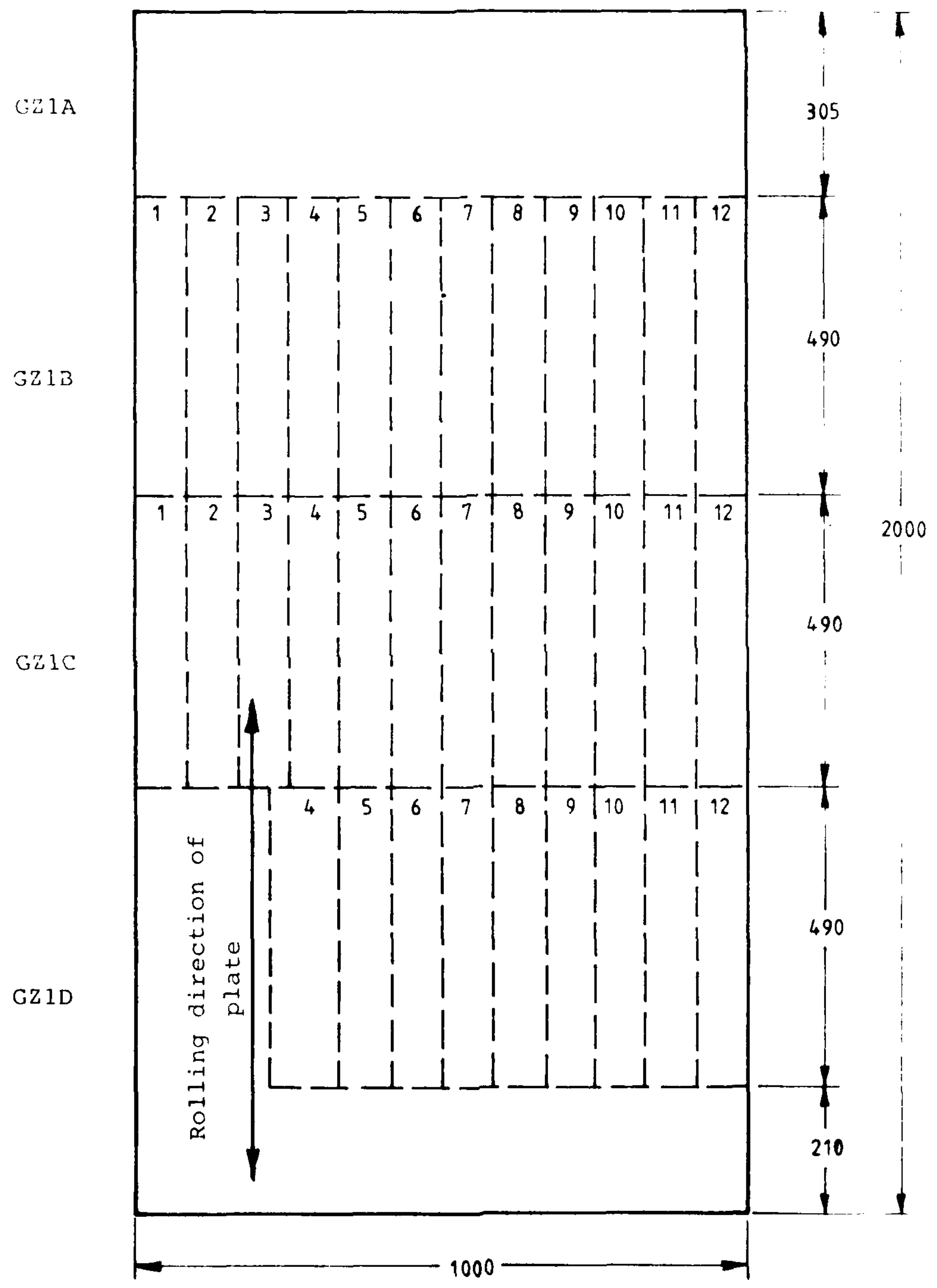


FIG. 7 FATIGUE SPECIMEN POSITIONS IN PLATE SERIAL NO. GZ1

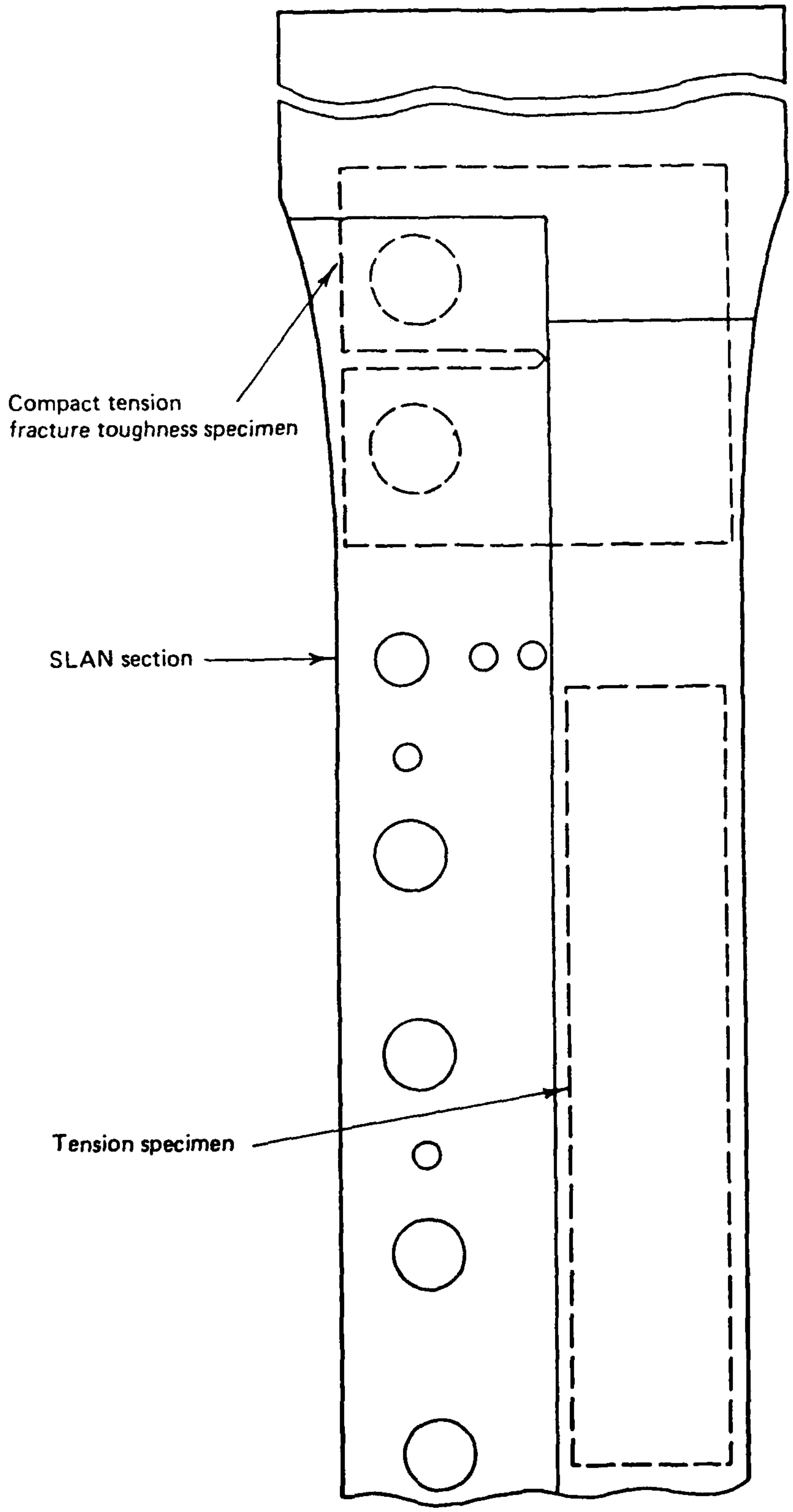


FIG. 8 LOCATIONS OF TENSION AND FRACTURE TOUGHNESS SPECIMENS

100 FLIGHTS (1989 CYCLES) REPRESENT 66.6 HOURS OF FLYING

FLIGHT A' →	10 CYCLES +3g/+1g	5 CYCLES +4g/+0.5g	2 CYCLES +5g/0g	1 CYCLE +6.5g/-1.5g	1 CYCLE +7.5g/-2.5g	1 CYCLE +6.5g/-1.5g	2 CYCLES +5g/0g	4 CYCLES +4g/+0.5g	1 CYCLE +3g/+1g
FLIGHT A →	10 CYCLES +3g/+1g	2 CYCLES +4g/+0.5g	2 CYCLES +5g/0g	2 CYCLES +6.5g/-1.5g	2 CYCLES +5g/0g	2 CYCLES +4g/+0.5g	5 CYCLES +3g/+1g		
FLIGHT B →	5 CYCLES +3g/+1g	5 CYCLES +4g/+0.5g	9 CYCLES +5g/0g	4 CYCLES +4g/+0.5g	5 CYCLES +3g/+1g				
FLIGHT C →	5 CYCLES +3g/+1g	1 CYCLE +4g/+0.5g	5 CYCLES +3g/+1g						

CYCLES OF +6.5g/-1.5g AND
+7.5g/-2.5g AT 1 Hz;
REMAINDER OF CYCLES AT 3 Hz

SEQUENCE OF FLIGHTS IN 100 FLIGHTS: 1 FLIGHT A', 18 FLIGHTS A, 36 FLIGHTS B AND 45 FLIGHTS C

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
B	C	C	B	C	C	C	A	C	C	B	B	A	C	C	C	B	A	C	B	B	B	A	C	C

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
C	A	A	C	C	B	B	B	C	B	A	B	C	C	B	A	A'	B	C	C	A	A	B	B	C

51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
C	B	C	C	B	C	B	B	C	C	C	A	B	A	C	C	C	B	A	B	B	B	C	B	C

76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
C	A	B	C	B	A	B	C	C	B	A	A	B	C	C	B	C	C	B	B	C	B	C	A	C

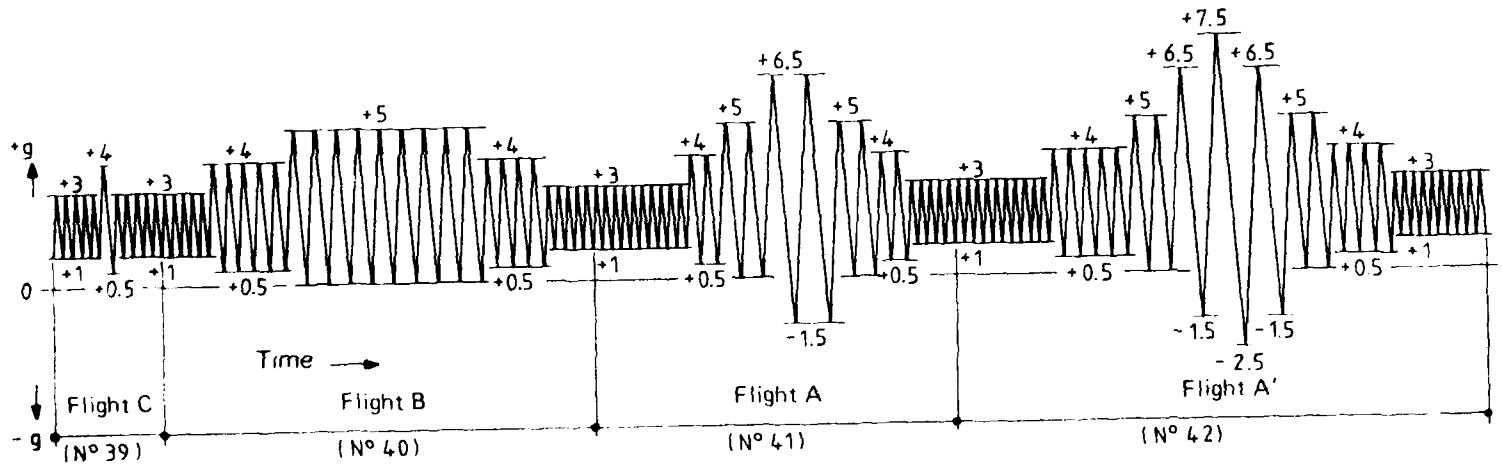
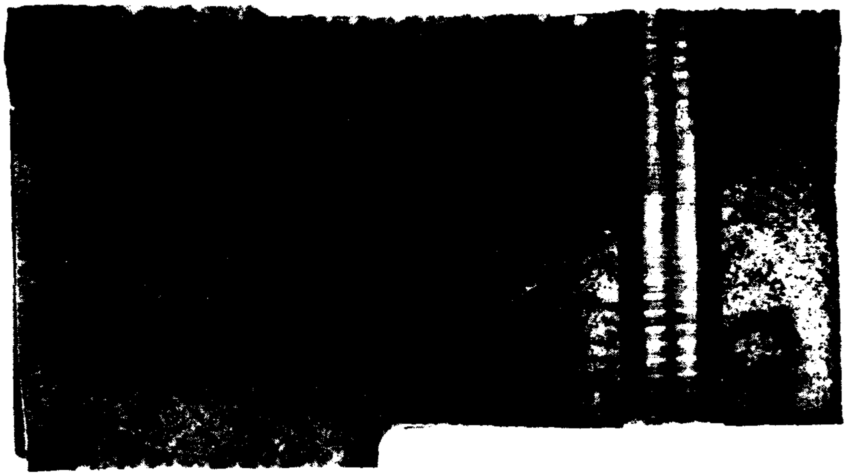


FIG. 9 FRENCH 100 FLIGHT MIRAGE III FLIGHT-BY-FLIGHT SEQUENCE

(a) "Control" Group E: GZ1B9

(b) Group A: Interference-fit steel pins in rivet holes and interference-fit bush in bolt hole, GZ1B7

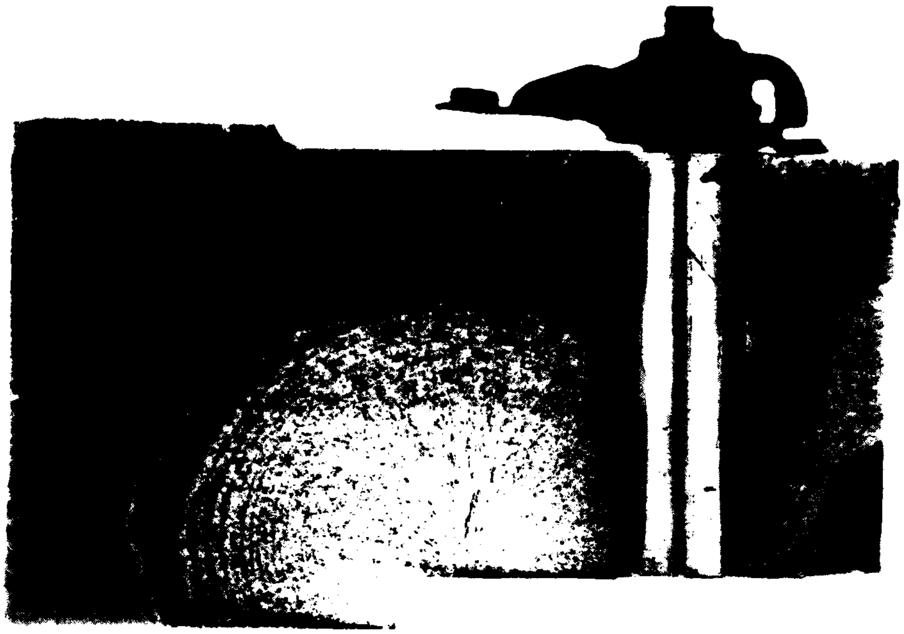
FIG. 10 FATIGUE FRACTURES (x2)



(c) Group B: Redesigned spar with reamed bolt hole, GZ1C7

(d) Group C: Redesigned spar with cold-expanded bolt hole, GZ1C1

FIG. 10 (cont.) **FATIGUE FRACTURES** (X2)



(e) Group C: Redesigned spar with cold-expanded bolt hole, GZ1B3 (Failure at hole (5))

(f) Group D: Redesigned spar with interference-fit steel bush in bolt hole, GZ135

FIG. 10 (cont.) FATIGUE FRACTURES (X2)

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Fatigue (materials)	Fasteners (interference),	11130
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Holes (openings),	Bushings,	
Cold working	Aluminium alloys,	
Aircraft structures	Mirage aircraft,	
	Adhesive bonding	

16. Abstract

Wing main spars of Mirage IIIO aircraft have undergone a refurbishment program to extend their fatigue lives by the installation of interference-fit steel bushes. A supplementary investigation has been carried out to assess two potential techniques for reducing the influence of empty rivet holes (namely the installation of interference-fit steel pins & adhesively-bonded aluminium rivets), and to assess the improvements in fatigue life which might be introduced by a redesign of the spar at the previously critical location.

It was found that both treatments of the rivet holes resulted in a further small improvement in the life of specimens

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16. Abstract (Contd)

refurbished with interference-fit steel bushes at the bolt holes, and that these lives were not significantly different from that of specimens of the new design of spar in which the cross-sectional area increased and the rivet holes omitted. However, considerable improvements in life were obtained when the bolt holes in the "redesigned spar" specimens were either cold-expanded (a factor of 4.1) or had interference-fit steel bushes installed in them (a factor of 3.4).

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